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14. ABSTRACT
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Abstract

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Statement of the problem studied

The aim of this project was to explore the influence of electron-electron interactions on electronic transport in a variety of circumstances. A central goal was to invent new physics based on analogies to spintronics. Spintronics is a well established field which explores the role of the spin degree-of-freedom in transport. The PI invented the phrase "pseudospintronics", which is now coming into common use, to refer to spintronics like phenomena in which the role of spin is taken over by some other two-valued quantum degree of freedom. In one key class of pseudospintronic phenomena, the role of spin is replaced by the layer degree-of-freedom in a two-layer system. Although progress was achieved by work supported by this grant, ideas are still evolving. This ARO supported grant has helped to nucleate the field of pseudospintronics.

Summary of Most Important Results

1. Pseudospintronics in Semiconductor Bilayers

The pseudospin degree of freedom in a semiconductor bilayer gives rise to a collective mode analogous to the ferromagnetic-resonance mode of a ferromagnet. In reference [1] we presented a many-body theory of the dependence of the energy and the damping of this mode on layer separation *d*. Based on these results, we discuss the possibilities of realizing transport-current driven pseudospin-transfer oscillators in semiconductors, and of using the pseudospin-transfer effect as an experimental probe of intersubband plasmons. A separate piece of work, still in progress [2] examines the role of electron-electron interactions in interlayer transport. The idea for the work in reference [2] was explained in the original proposal for this grant. We expect that interaction effects can give rise to non-linear I-V characteristics similar to those seen in the quantum Hall regime[3]. The project has turned out to be more subtle than anticipated because of the interplay between interaction effects and single-electron resonant tunneling effects. A draft of a long paper for Physical Review B is nearly ready for submission.

2. *Transport in Nanoparticle Arrays*

In reference [4] we reported on a detailed study of the transport properties of one-dimensional metallic nanoparticle arrays. Our study focused on the physics which controls threshold voltages and on the spatial distribution of potential drops across the array both below and above threshold. We studied dependences on array parameters and analyzed the roles of charge and resistance disorder. We considered the case in which the interaction between charges is local and the case of long-ranged interactions separately. We showed that some of the differences between the transport properties of arrays with short and long-range interactions are due to interactions between charges in different nanoparticles, while others are due to interactions between charges in the islands and those at the electrodes which produce a polarization potential drop through the array. Finally we studied how strong disorder due to charged impurities trapped in the substrate is partially screened by redistribution of charges among the nanoparticles and demonstrated that long-range interactions induce correlations in the screened disorder potentials of neighboring islands.

3. *Pseudospin Order in Two-Layer Graphene Systems*

In reference [5] we predicted that neutral graphene bilayers are pseudospin magnets in which the charge density contribution from each valley and spin spontaneously shifts to one of the two layers. The band structure of this system is characterized by a momentum-space vortex, which is responsible for unusual competition between band and kinetic energies, leading to symmetry breaking in the vortex core. We discussed the possibility of realizing a pseudospin version of ferromagnetic metal spintronics in graphene bilayers based on hysteresis associated with this broken symmetry. The origin of the instability we discuss is the quadratic band crossing which occurs in AB stacked graphene bilayers. Our work on this topic has since been expanded in several directions by other researchers. For example Kivelson and collaborators [6] have examined this type of instability from a general point of view. Levitov and collaborators [7] have rediscovered our results, viewing the instability as a type of ferroelectricity. McCann [8] has studied a more modest version of graphene bilayer pseudospintronics based on single-particle physics alone. We have also explored [9,10] a distinct type of instability which can occur in a two-layer graphene system in which the layers are separated by a dielectric. In this case bilayers can exhibit spontaneous coherence [3] which is equivalent to XY-type pseudospin ferromagnetism.

4. *Disorder and Transport in Graphene Sheets*

As a natural outgrowth of our work on pseudospintronics in two-layer graphene systems we became interested in understanding the disorder present in graphene systems on substrates and on the influence of electron-phonon scattering on a number of transport properties of graphene systems. We have contributed a number of articles to this active topic, including a study of the way STM momentum-space maps see disorder [11] and a proposal for an approximate density-functional method for including interaction effects in disordered systems [12].

5. *Magnetism in Graphene Nanostructures*

According to mean field theory a graphene nanoribbon with zigzag edges has a gapped magnetic ground state. Many researchers believe that this property may be responsible for the poorly controlled magnetism [13} which seems to appear commonly in graphitic nanostructures. with an antiferromagnetic interedge superexchange interaction. We [14] have developed a theory of antiferromagnetic interactions between spins on opposite sides of a graphene ribbon. The theory is based on the asymptotic properties of the Dirac-model ribbon wave function. We find that, unlike the case of conventional atomic-scale superexchange, opposite spin orientations on opposite edges of the ribbon arefavored by both kinetic and interaction energies. We have also extended this study to examine [15] the sensitivity of ribbon magnetism to doping.

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